CHAPTER-1

INTRODUCTION
Plastics are widely used in different applications. Food packaging is one of the most important applications. The use of plastic for packaging are increasing rapidly all over the world because they are light weighted, can be molded into any shape, non-corrosive in nature, variety of colors etc. The primary function of packaging is to protect the food from external environment, maintaining hygienic conditions, conserving its purity, quality and safety. Almost one-fifth of the net revenue of the plastic industry is from food packaging industry. The use of packaging is usually seen as an indicator of growth and economic welfare. By studying the relation between a country’s GDP (Gross Domestic Product) and packaging consumption, it may be concluded that the richer the nation, the higher the quantity and quality of packaging introduced in the market. Contrarily, the consumption of plastic packaging is always rapid and soon becoming environmental packaging wastes because they are associated with consumption of non-renewable raw materials.

The main issue associated with packaging is food packaging material (FPMs) interaction because FPMs have the potential to release and successive transfer of components into the packaged content. In this way, FPMs contaminate the stored commodity with the risk of toxic health hazard for the consumer. The substance migrating from FPMs can be subdivided into two category and these are Intentionally added substances (IAS) and Non-intentionally added substances (NIAS). IAS are derived directly from the FPMs i.e., they are identical to the FPM such as metals, plastic monomers, antioxidants, etc. NIAS are those compounds which have not been added intentionally to the FPM during the preparation of the FPM or it might have been added to that portion of FPM, which may not come in contact with the food.

Examples of IAS include plastic monomers such as vinyl chloride (from PVC), caprolactum (from polyamide), metals (from stabilizer) and bisphenol-A and phthalate (from plasticizer) etc. Examples of NIAS include formation of acetaldehyde and
formaldehyde as thermal degradation products from polyethylene terephthalate and formation of 2,4-diterbutylphenol(2,4 DTB) and 2,6-diterbutyl-p-benzoquinone(2,6-DTBQ) as oxidation products from Irgafos 1010 and Irgafos 168, or both antioxidants etc.

1.1 Food Packaging plastics and their properties

The commonly used plastics for food packaging applications are:

- Polyethylene terephthalate (PET)
- High-density polyethylene (HDPE)
- Polyvinyl chloride (PVC)
- Low-density polyethylene (LDPE)
- Polypropylene (PP)
- Polystyrene (PS)
- Polycarbonate (PC) (Bell, 1982)

Each food packaging plastic has its own unique properties.

1.1.1 Polyethylene terephthalate (PET)

PET is also known as Dacron and Terylene. It is the most common thermoplastic polymer of the polyester family and is used in packaging. It is formed by condensation polymerization of ethylene glycol and terephthalic acid. The condensation polymerization reaction for PET is shown in Fig 1.1.

![Fig. 1.1- Chemical reaction involving preparation of PET](image)

Fig. 1.1- Chemical reaction involving preparation of PET
It has very good tensile and yield strength properties but it melts very easily which makes it suitable for cold beverages (Girija, 2005). It can be transparent or opaque. It is used to make soft drink, water, sports drink, ketchup, and salad dressing bottles, and peanut butter, pickle, jelly and jam jars.

1.1.2 High-density polyethylene (HDPE)

HDPE is polyethylene thermoplastic polymer used in packaging. HDPE is produced mainly by two methods. The first method is the coordination polymerization of the ethylene by triethyl aluminium and titanium tetrachloride. In the second method, the polymerization is carried out with the help of metal oxide catalysts such as Cr or Mo oxides supported over alumina-silica bases. In both the methods, the polymerization is carried out at relatively low pressure.

HDPE is used for clouded containers or bottles for foods such as milk where a strong material is only required, but the transparency is not as great factor (Bell 1982, Li Tieqi, 2007). It is stiff and has good tensile strength and hardness, but is not heat stable (i.e. it melts at a relatively low temperature). It is used to make milk, oil and juice bottles, supermarket bags, cleaning product containers, motor oil containers, agricultural films and chemical containers etc.

1.1.3 Polyvinyl chloride (PVC)

PVC is a thermoplastic polymer, commonly used for clear plastic wrapping. Polyvinyl chloride is formed by addition polymerization of vinyl chloride as shown in Figure 1.2.

![Chemical reaction involving preparation of PVC](image)

**Fig 1.2- Chemical reaction involving preparation of PVC**
It is flexible, light, cost-effective, transparent, tough and have excellent organoleptic properties (does not affect the taste of the packaged food), and can be easily extrude into sheets (Pearson,1982). PVC are also used for packaging of disposable syringes and medical devices, and during food material transportation, handling and cling film for meat, fish, cheese etc.

1.1.4 Low-density polyethylene(LDPE)
LDPE is a thermoplastic polymer used in food storage bags. LDPE is produced by the high pressure polymerization of ethylene, using oxygen as an initiator.

It is very flexible and less dense as compare to HDPE. It has a large stretch capacity and excellent chemical and moisture resistance (Bell 1982, Pedroso 2005). Low-density polyethylene is relatively transparent. LDPE exhibit inertness to chemicals and also resistance to breakage which make it suitable for use in squeeze bottles and in many attractive containers. Most of the films are not heat stable and may melt into the food.

1.1.5 Polypropylene (PP)
PP is a thermoplastic polymer and is used in packaging of rigid containers like baby bottles, cups and bowls etc (Sahin,2005). Polypropylene (PP) is produced by the addition polymerization of propylene using the Ziegler-Natta catalysts.

\[
\text{Propylene} \quad \overset{n \text{ CH}_2 = \text{CH}_3}{\longrightarrow} \quad \text{Polypropylene} \quad \overset{\text{CH} = \text{CH}_2 \quad \text{CH}_3}{\longrightarrow}n
\]

**Fig 1.3- Chemical reaction involving preparation of PP**

Polypropylene is semi-rigid, translucent, tough, and has good chemical and heat resistance so is used for microwavable packaging and sauce or salad dressing containers.
1.1.6 Polystyrene (PS)

PS also known as polyvinyl benzene, is a thermoplastic polymer and commonly used in Styrofoam food containers and cups and also in meat and egg trays that require a rigid form or heat resistance (Bell 1982, Bernardin 2007). PS is produced by addition polymerization of styrene.

![Chemical reaction involving preparation of PS](image)

Polystyrene is an amorphous polymer that is glassy, brittle and has low strength, but it is hard and stiff.

1.1.7 Polycarbonate (PC)

PC is a group of thermoplastic polymer containing phenol and carbonic acid in their chemical structures. The polycarbonate is prepared by the reaction of bisphenol-A and phosgene as shown below.

![Chemical reaction involving preparation of PC](image)

It is transparent, heat resistant, durable and often used to form refillable water bottles, sterilisable baby bottles, microwave ovenware, eating utensils, plastic coating for...
metal cans. Very small amounts of bisphenol-A are formed when polycarbonate bottles are washed with harsh detergents or bleach (e.g., sodium hypochlorite). The exposure of human to high levels of bisphenol-A is potentially hazardous and causes various health problems.

All these polymeric materials protect the food it contain, but often deficient to provide mechanical and barrier properties and give less support to prevent damage (Birley, 1982).
Table 1.1 - Mechanical Properties of Common Food Plastics. (Birley, 1982)

<table>
<thead>
<tr>
<th>Material Characteristic</th>
<th>PET</th>
<th>HDPE</th>
<th>PVC</th>
<th>LDPE</th>
<th>PP</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>1.35</td>
<td>0.959</td>
<td>1.3-1.58</td>
<td>0.925</td>
<td>0.905</td>
<td>1.05</td>
</tr>
<tr>
<td>Modulus of Elasticity (GPa)</td>
<td>2.76-</td>
<td>1.08</td>
<td>2.41-4.14</td>
<td>.172-.282</td>
<td>1.14-</td>
<td>2.28-</td>
</tr>
<tr>
<td></td>
<td>4.14</td>
<td></td>
<td></td>
<td></td>
<td>1.55</td>
<td>3.28</td>
</tr>
<tr>
<td>Yield Strength (MPa)</td>
<td>59.3</td>
<td>26.2-33.1</td>
<td>40.7-44.8</td>
<td>9.0-14.5</td>
<td>31.0-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>37.2</td>
<td></td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>48.3-72.4</td>
<td>22.1-31.0</td>
<td>40.7-51.7</td>
<td>8.3-31.4</td>
<td>31.0-</td>
<td>35.9-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>41.4</td>
<td>51.7</td>
</tr>
<tr>
<td>Percent Elongation (%)</td>
<td>30-300</td>
<td>10-1200</td>
<td>40-80</td>
<td>100-650</td>
<td>100-600</td>
<td>1.2-2.5</td>
</tr>
<tr>
<td>Fracture Toughness (MPa sqrt (m))</td>
<td>5</td>
<td>-</td>
<td>2.0-4.0</td>
<td>-</td>
<td>3.0-4.5</td>
<td>0.7-1.1</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion (10⁻⁶ (°C)-1)</td>
<td>117</td>
<td>106-198</td>
<td>90-180</td>
<td>180-400</td>
<td>146-180</td>
<td>90-150</td>
</tr>
<tr>
<td>Thermal Conductivity (W/mK)</td>
<td>0.15</td>
<td>0.48</td>
<td>0.15-0.21</td>
<td>0.33</td>
<td>0.12</td>
<td>0.13</td>
</tr>
<tr>
<td>Specific Heat (J/kgK)</td>
<td>1170</td>
<td>1850</td>
<td>1050-1460</td>
<td>2300</td>
<td>1925</td>
<td>1170</td>
</tr>
</tbody>
</table>
As we know that plastics used for packaging are made from different type of polymers. The question arises here is that how can we determine which type of plastic we are using. For this, Society of Plastics Industry (SPI) has developed SPI resin identification codes to identify the polymer type of plastics and is used internationally (ASTM, 2016). The main purpose of this codes is to allow recyclers to efficiently identify plastic items that could be recycled.

**Table 1.2- SPI Resin Identification codes** (SPI Code, 2016)

<table>
<thead>
<tr>
<th>Recycling number</th>
<th>Image</th>
<th>Polymer name</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image1.png" alt="Image" /></td>
<td>Polyethylene terephthalate</td>
<td>PETE/PET</td>
</tr>
<tr>
<td>2</td>
<td><img src="image2.png" alt="Image" /></td>
<td>High-density polyethylene</td>
<td>HDPE</td>
</tr>
<tr>
<td>3</td>
<td><img src="image3.png" alt="Image" /></td>
<td>Polyvinyl chloride</td>
<td>PVC</td>
</tr>
<tr>
<td>4</td>
<td><img src="image4.png" alt="Image" /></td>
<td>Low-density polyethylene</td>
<td>LDPE</td>
</tr>
<tr>
<td>5</td>
<td><img src="image5.png" alt="Image" /></td>
<td>Polypropylene</td>
<td>PP</td>
</tr>
<tr>
<td>6</td>
<td><img src="image6.png" alt="Image" /></td>
<td>Polystyrene</td>
<td>PS</td>
</tr>
<tr>
<td>7</td>
<td><img src="image7.png" alt="Image" /></td>
<td>Other plastics, such as polycarbonate, acrylic, polylactic acid and multilayer combinations of different plastics.</td>
<td>O</td>
</tr>
</tbody>
</table>
1.2 Food regulations

During the last years, the exposure to toxic chemicals contained in food packaging containers has received special attention. Migration of toxic chemicals from food packaging polymer into the food constitutes a category of pollutants that cannot be neglected. These pollutants contaminate the food with the risk of toxic health hazard for the consumer. Therefore, the guidelines for the suitable use of plastic for food packaging application have been formulated all over the world. To safeguard the health of a consumer against potential hazard of substances that migrate into the food, the European Union (EU), U.S.A (U.S. Pharmacopoeia 1995, British Pharmacopeia 1998, EU 2004, EU 2008, EU 2011) and many other countries including India have provided the standards. In India, Bureau of Indian Standards (BIS), provide the national standards. These regulations provide the rules for proper use of plastic for food packaging applications.

- **BUREAU OF INDIAN STANDARDS: 9833-1981**: List of pigments and colorants for use of plastics in contact with foodstuffs, pharmaceuticals and drinking water.

- **BUREAU OF INDIAN STANDARDS: 9845-1998**: Method of analysis for the determination of specific and/or overall migration of constituents of plastics materials and articles intended to come into contact with food stuffs.

- **BUREAU OF INDIAN STANDARDS: 10141-1982**: Positive list of constituents of polyethylene for its safe use in contact with foodstuffs, pharmaceuticals and drinking water.

- **BUREAU OF INDIAN STANDARDS: 10142-1982**: Specification for styrene polymers for its safe use in contact with foodstuffs, pharmaceuticals and drinking water.

- **BUREAU OF INDIAN STANDARDS: 10146-1982**: Polyethylene for its safe use in contact with foodstuffs and drinking water.
BUREAU OF INDIAN STANDARDS: 10148-1982: Positive list of constituents of polyvinyl chloride and its copolymers for safe contact with foodstuffs, pharmaceuticals and drinking water.

BUREAU OF INDIAN STANDARDS: 10149-1982: Positive list of constituents of styrene polymers in contact with foodstuffs, pharmaceuticals and drinking water.

BUREAU OF INDIAN STANDARDS: 10151-1982: Polyvinyl chloride (PVC) and its co-polymers for its safe use in contact with foodstuffs, pharmaceuticals and drinking water.

BUREAU OF INDIAN STANDARDS: 10910-1984: Positive list of constituents of Polypropylene and its copolymers for its safe use in contact with foodstuffs, pharmaceuticals and drinking water.

BUREAU OF INDIAN STANDARDS: 11434-1985: Ionomer resins for its safe use in contact with foodstuff, pharmaceuticals and drinking water.

BUREAU OF INDIAN STANDARDS: 11435-1985: Positive list of constituents of ionomer resins in contact with foodstuffs, pharmaceuticals and drinking water.

BUREAU OF INDIAN STANDARDS: 11704-1986: Ethylene acrylic acid (EAA) copolymers for their safe use in contact with foodstuffs, pharmaceuticals and drinking water.

BUREAU OF INDIAN STANDARDS: 11705-1986: Positive list of Ethylene acrylic acid (EAA) copolymers in contact with foodstuffs, pharmaceuticals and drinking water.

BUREAU OF INDIAN STANDARDS: 12229-1987: Positive list of constituents of polyalkylene terephthalates (PET & PBT) for their safe use in contact with foodstuffs, pharmaceuticals and drinking water.
BUREAU OF INDIAN STANDARDS: 12247-1988: Nylon-6 polymer for its safe use in contact with foodstuffs, pharmaceuticals and drinking water.

BUREAU OF INDIAN STANDARDS: 12248-1988: Positive list of constituents of Nylon-6 polymer for its safe use in contact with foodstuffs, pharmaceuticals and drinking water.

BUREAU OF INDIAN STANDARDS: 12252-1987: Polyalkylene terephthalates (PET & PBT) for their safe use in contact with foodstuffs, pharmaceuticals and drinking water.

BUREAU OF INDIAN STANDARDS: 13449-1992: Positive list of constituents of ethylene vinyl acetate (EVA) copolymers in contact with foodstuffs, pharmaceuticals and drinking water.

BUREAU OF INDIAN STANDARDS: 13576-1992: EMA for its safe use in contact with foodstuffs, pharmaceuticals and drinking water.

BUREAU OF INDIAN STANDARDS: 13601-1993: Ethylene vinyl acetate (EVA) co-polymers for its safe use in contact with foodstuffs, pharmaceuticals and drinking water.


BUREAU OF INDIAN STANDARDS: 10142-1999: Polystyrene (crystal and high impact) for its safe use in contact with foodstuffs, pharmaceuticals and drinking water.

BUREAU OF INDIAN STANDARDS: 14972-2001: Positive list of constituents of polycarbonate in contact with foodstuffs, pharmaceuticals and drinking water.
The mentioned standards provide requirement of basic resin, additives, monomers, pigments, colorants, overall migration, storage and control.

In order to identify the potential risk regarding migration of toxic chemicals into the food, it is necessary to know the identity of the material, their additives and qualitative and quantitative migration of substance into stored commodity. Various researches have been done on migration of toxic additives into the food and found that concentration of toxic chemicals migrate into the food were above allowed limit as per guidelines.

1.3 Plastic and their additives

A polymer (Greek poly = "many" + mers = "parts") is a large molecule, or macromolecule, consist of many repeated subunits known as monomers. Polymers are formed by polymerization of repeated monomers. All polymer apart from basic monomers, contain an additional components called additives which are added in small amount generally from traces (µg/Kg) to a few percent levels, to complete their physical and chemical properties or to improve their processibility and functionality of the plastic (Deanin 1975, Arnold 1968). The commonly used additives are fillers, plasticizers, antiblock agents, antioxidants, lubricants, antistatic agents, etc.

Each of the additives has its own unique characteristics properties. Fillers and plasticizers are used at high concentration to increase volume or weight, to enhance softening, flexibility, elasticity, malleability and processibility of plastic. All others additives used are mostly low molecular weight components like stabilizers, anti-oxidant and anti-static agents, light stabilizers (UV absorbers), lubricants (slip agents), optical brighteners, etc. Plastics may also contain small quantities of polymerisation residues including monomers, oligomers (with a molecular weight up to about 200), polymerization catalyst (mainly metallic salts and organic peroxides), solvents, emulsifiers and wetting
agents, raw material impurities, plant contaminants, inhibitors, decomposition and side reaction products. The final groomed plastic is somewhat different from the pure polymer as it contains different types of additives for various applications. A brief account of the functions of some major additives is given below:

1.3.1 Fillers
Fillers are mainly common inorganic mineral powders which are added to improve processing, rigidity, dimensional stability, hiding power, and reduce manufacturing costs. As common inorganic mineral powders, they do not cause any new health hazard for the consumer. The most commonly used fillers are calcium carbonate, gypsum, clays, carbon black and alumina trihydrate, often used in quantities exceeding the polymers themselves. The maximum use is in vinyl, with smaller amount in polyesters and other plastics types.

1.3.2 Antiblock Agents
Blocking is the sticking of two adjacent layers of film. It is the most common problem related with polyethylene and polypropylene films. For this antiblock agents are added to roughen the surface of adjacent thin films and hence, to prevent them from adhesion during machine processing. The most commonly used antiblock agent is silica because of its poor solubility in most polymers which helps to elevate the surface concentration and produces irregularity. Similarly, fatty acids and amides are slip additives used to reduce mobility.

1.3.3 Antioxidants
Antioxidants are added to prevent degradation of the polymer by reacting with atmospheric oxygen during molding process at high temperatures or when used in contact with hot foods and to prevent deterioration during storage. The most frequently used antioxidants are derivatives of phenols and organophosphite. Some of these substances are classified as heat stabilizers.
Fig 1.6- Common antioxidants Irganox 1010(I1010) (a) and Irgafos 168(I168) (b).

1.3.4 Antistatic Agents

Since all plastics are good electrical insulators, they will retain electrostatic charges produced by friction from contact with processing machinery. Accumulation of the static electricity can cause problems through the pick-up of dust, adhesion between layers or
particles of plastics, sparking, electrical shock and possibly fire hazards. Most antistatic agents are glycol derivatives or quaternary ammonium compounds.

1.3.5 Plasticizers

Plasticizers are added to make the plastics more flexible and less brittle. They are generally high molecular weight esters. They also serve the material the limp and tacky qualities found in “cling” films. About 90% of all plasticizers are used in PVC. Typically, phthalic esters such as dioctyl phthalate (DOP), also known as di-2-ethylhexyladipate (DEHA) are used as plasticizers.

Fig 1.7-Common plasticizers di-2-ethylhexyladipate (DEHA) (a) and dioctyl phthalate (DOP) (b).
1.3.6 Lubricants

Lubricants are added to plastics to reduce frictional forces and are usually low to medium molecular weight hydrocarbons. They should have good solubility with the plastic, minimum volatility and be relatively stable compounds.

1.3.7 UV Stabilizers

UV Stabilizers are added to protect the plastics from deterioration by sunlight or even supermarket lighting. Products containing vitamin C are susceptible to this type of deterioration. The commonly used UV stabilizers are derivatives of benzophenones, benzotriazoles, phenyl esters, diphenylacrylates, etc.

![Benzophenone](a) ![Benzotriazole](b)

**Fig- 1.8 Common UV Stabilizers Benzophenone (a) and Benzotriazoles 2-(2-Hydroxy-5-methylphenyl)benzotriazole (b).**

1.3.8 Heat Stabilizers

Heat stabilizers are added to polymer to prevent them from degradation that occur during high temperature processing and fabrication. Largest use is in PVC. The most commonly used heat stabilizers include family of lead salts, complex of barium cadmium solids, nontoxic salts of Ca and Zn etc.
1.3.9 Optical Property Modifiers

The optical properties of a material from a technological point of view are normally described in terms of their ability to transmit light, to exhibit colour and reflect light from surface (i.e., gloss). The majority of food packaging films are non-pigmented, but some are coloured by the addition of colorants. The principal pigments used as colourants in packaging are carbon black, white titanium dioxide, red iron oxide, yellow cadmium sulphide, molybdate orange, ultra blue, blue ferric ammonium, ferrocyanide, chrome green, and blue and green copper phthylocyanines.

1.3.10 Fire Retardants

Most thermoplastics being an organic compound burns or decompose on exposure to fire and produce toxic fumes. Fire retardants are added to polyolefins, polycarbonate, polyamides, polyesters and other polymers to prevent ignition or spread of flame. The most commercially used flame retardants include brominated and chlorinated types, phosphorus based types, and metallic oxides such as aluminum trihydrate, magnesium hydroxides, etc.

1.3.11 Foaming Agents

Foaming or blowing agents are used for the production of cellular products from liquid plastic resin and are generally classified into physical and chemical types. In physical type, the generation of gases to produce the cells takes place through a physical transition i.e., evaporation or sublimation. And in chemical type, a chemical process i.e., decomposition takes place which result in evolution of gases. In food packaging applications, physical blowing agents are normally used. For example, expanded and extruded polystyrene foams use a fluoro carbon or light aliphatic hydrocarbon such as pentane as the blowing agent.
1.3.12 Antimicrobial Agents

Antimicrobial agents such as algaecides, fungicides and bactericides are added to plastics to prevent the growth of micro-organisms. However, their use in food packaging is rare because of the probability of migration into the food itself.

1.3.13 Impact modifiers

Impact modifiers are added to polymer to provide breakage resistance, rigidity, ease of post fabrication, strength to sheets. The strength provided to the plastics depends on time and temperature conditions of processing. Rigid PVC for prolonged outdoor exposure require impact modifier. Similarly, epoxy and polyester thermosets need impact modifier. The most commonly used impact modifiers are ABS (acrylonitrile-co-butadiene-co-styrene), acrylic, methacrylate-butadiene-styrene, ethylene vinyl acetate and chlorinated polyethylene.

1.4 Migrating Components in Plastic Packages

Additives are incorporated into polymers to alter and improve basic mechanical, physical or chemical properties. Additives are used to protect the polymer from the degrading effects of light, heat, or bacteria or to change polymer processing properties such as melt flow; to provide product color; and to provide special characteristics such as improved surface appearance, reduced friction, and flame retardancy. In addition to provide plastic materials desirable packaging qualities, these additives also have negative environmental and human effects (Chawala 1991, Demore 2002, Pearson 1993). Plastic containers can contaminate food because some chemicals migrate from the packaging polymer into the food they contain. Monomers, oligomers, additives, stabilizers, plasticizers and lubricants have potential to migrate into the food. Migration of chemicals from food packaging polymers into the food should be checked to ensure that the amount of migrating
components must strictly follow the standard sets by various regulatory agencies. The migration depends upon several factors such as temperature-time condition, surface area of contact and types of components in packaging material, and type of foodstuff (Barnes 2007, Veraart 2007, Khaksar 2009). Small molecules, typically monomers and residual solvents, with low boiling point will migrate fast. Some gaseous monomers such as formaldehyde, vinyl chloride, ethylene and butadiene have a high tendency to migrate quickly even at ambient temperatures and for sure at 100°C. A high molecular weight means a large molecule and a slow migration rate and vice versa. Molecules which have a low solubility in the plastic will migrate faster than molecules with a high solubility in the plastic. Some organometallic substances will migrate due to fairly low boiling points, e.g. organotin compounds. Inorganic pigments, (such as carbon black), fillers and reinforcing fibres will not migrate unless the plastic material is degraded by weathering or chemical attack. Migration rate will increase with increase in temperature. Migration rate will increase to a contact medium if the solubility of the migrating substances is high in the contact medium (e.g. phthalate plasticizers to vegetable oils) and will decrease with time as the concentration of the migrating substances get lower in the plastic.

1.4.1 Migration of specific components

1.4.1.1 Plasticizers

People are exposed to chemicals from plastic multiple times in a day through the air, dust, water, food and use of consumer products. For example, phthalates are used as plasticizers in the manufacturing of vinyl flooring and wall coverings, food packaging and medical devices. Eight out of every ten babies, and nearly all adults, have measurable levels of phthalates in their bodies, according to one study. Phthalates are not chemically bounded to plastic matrix and migrated when they
come in contact with lipophilic substances. They are also liberated into environment during production, its use and also after disposal of plastics containing phthalate (Staples, 1997).

Plasticizers are a low molecular weight compound and have potential to migrate into the wrapped food, hence become indirect food additives (Goulas, 1998). PVC, PVA and PE contain plasticizers such as phthalate and adipate and their migration into the food under various conditions have been reported (Castle 1990, Lau OW 1996, Gaulas 2000, Fankhauser-Noti 2006, Gaulas 2007, Biedermann 2008, Wei DY 2009, Guoz 2010).

Migration of several plasticizers in contact with oily food has been reported from plastic gaskets (Fankhauser-Noti 2006, Ežerskis Z 2007). In another study, migration of phthalate from plastics in contact with cooking oil and mineral water under different storage conditions have been reported (XuQ, 2010). Generally, the migration of plasticizers depends upon composition of food, temperature-time condition and initial concentration of migrating substances in the film (Badeka BA, 1996). Commercial cling films made from PVC – DEHA (diethylhexyl adipate) is a food-compatible phthalate plasticizer and tiny amounts may migrate into fatty food (such as meat or cheese), especially on heating. DEHP (diethylhexyl phthalate) is another plasticizer that has been a concern because it can migrate, and for this reason it is not used in food-related products in USA.

The debate about phthalates, specifically those with low molecular weight such as DEHP (diethylhexyl phthalate), DBP (di-n-butyl phthalate), and BBP (butyl benzyl phthalate), have been going for years. They are known as endocrine disruptors as they are also accused of messing with hormones and causing girls to
reach puberty earlier, as well as reducing sperm count in boys. Phthalates have also been linked to allergies and asthma.

1.4.1.2 Antioxidants

The migration of antioxidants has been widely studied in polypropylene and polyolefin and generally occurs during processing and storage (Goydan R 1990, Jeon DH 2007, Beldi G 2012, Gao Y 2011). Several studies have reported the migration of antioxidants and their degraded product from different packaging polymer under various conditions (Beldi G 2012, Gao Y 2011, Jickells SM 1992, Garde JA 2001, Dopico-Garcia 2003, Alin J 2010, Reinas I 2012). A well-known antioxidant is tris (nonylphenyl) phosphite (TNPP) which consists of three units of nonylphenol (NP) per molecule of this agent. Initially, these materials were considered inert. Since the latest discovery of their ability to be endocrine disrupters, increased the concern for human to the exposure of this chemical. Migration of NP from HDPE containers to milk surrogate was also estimated and found that the amount of NP migrate into the milk might be similar to that of the bottled water (Reinas, 2012).

It is also reported that heating in microwave for a long time (1 hour) causes more degradation of antioxidant in food simulants as compared to conventional heating using oil bath (Alin J, 2011).

1.4.1.3 Monomers and Oligomers

Various studies have reported the migration of styrene into the food (Lickly TD 1995, Nerin C 1998, Tawfik MS 1998, Jin OC 2005, Khaksar MR 2009). Styrene, a residual monomer found in polystyrene (PS) is a well-known human carcinogen. PS used in a variety of applications include cups, packaging trays etc., and migration of
styrene to hot drinks (tea, milk, cocoa in milk) was highly depend upon temperature of drinks and fat content and it was also found that highest level of migration in hot cocoa (Khaksar MR, 2009). It was also reported that styrene migration increases with increasing fat content (Tawfik MS, 1998).

In addition, bisphenol-A (BPA), found in polycarbonate bottles and the linings of food and beverage cans, can leach into food and drinks (Biles JE, 1997, Goodson A 2002, Kubwabo C, 2009, Nam SH, 2010). The U.S. Centers for Disease Control and Prevention reported that 93 percent of people had detectable concentration of BPA in their urine. The report also suggested that the high exposure of BPA and phthalates to the premature infants in neonatal intensive care units is of great concern. Also, people with the highest exposure to BPA have an increased rate of heart disease and diabetes, according to one recent study. Bisphenol-A may act as an endocrine disruptor and causes developmental and neurological impacts. The release of BPA increases with repeated use of PC bottles (Nam SH, 2010). According to European Union (EU) 321/2011 regulation, bisphenol-A is restricted for the preparation of polycarbonate bottles used for infant feeding. A report of the Berkeley (U.S.) Plastics Task Force published in 1996 found that styrene from polystyrene, plasticizers from PVC, antioxidants from polyethylene and acetaldehyde from PET have the ability to contaminate food.

1.4.1.4 Stabilizers

Stabilizers (organometallic compounds, fatty acids and inorganic oxides) have the highest degree of toxicity and if these are used in association with a plasticizer in a plastic formulation, the toxicity potential is greatly increased (Wallace L, 1968).
1.4.1.5 Heavy metals

Many chemical additives can cause direct toxicity as in the case of metals such as lead, cadmium and mercury. Some metals like Fe, Zn, Cu, Co, Cr, Mn, Ni, are required in small quantities for human metabolism, but at higher levels they can cause toxicity. Other metals like lead, mercury, cadmium, and arsenic etc. have no useful role and are completely toxic. In the manufacturing of thermoplastic polymers, such as Polyvinyl chloride (PVC), Polyethylene terephthalate (PET), High density polyethylene (HDPE), Low density polyethylene (LDPE), Polypropylene (PP), Polystyrene (PS), Polycarbonate (PC) etc., various catalysts are used that can contain low levels of metals. Heavy metals such as zinc, nickel, manganese, copper, chromium, cadmium, lead, antimony etc., present in packaging as additives. Cadmium and lead are present in inorganic pigments and stabilizers. Thermal stabilizers may include nickel, lead and antimony while antioxidants can contain nickel. Additives used as pigments often contain metals like lead, tin, arsenic, nickel, cadmium, barium, aluminium, titanium, iron etc. Generally, these elements are added as compounds, which often do not chemically bond to the matrix of the polymeric materials and diffuse out under the influence of physicochemical factors such as sunlight, temperature, and type of solvents and pH of the stored commodity.

Migration of heavy metals, such as Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn into the simulating solvents from the finished plastic materials was also reported (Srivastava SP 1984, Ulsaker GA 1977). This can disturb the normal physiological activities of the body cells and other organs, as the concentration of these metals were found above the allowed limits.
Of the additives especially metals to plastic, the most thoroughly researched by health experts is lead. While the amount of lead in these products is variable, no level of lead is safe for young children. Acute lead poisoning may cause severe headaches, irritability, abdominal pain and various symptoms associated with the nervous system (Jarup L, 2003). Exposure or ingestion to high levels of lead can cause severe brain damage in children and acute memory loss in adults(OEHHA, 2011). Long time exposure to lead can cause stomach and lungs cancer (Jarup L, 2003). It was reported by physician and scientist that no percentage of lead in blood is safe (NRC, 2009).

Prolonged exposure to cadmium may cause kidney and skeletal damage (Jarup L, 2003). Cadmium exposure has also been related to chronic renal failure and reduces the glomerular filtration rate.

The exposure of chromium and nickel in both adults and children have been associated with developmental problems (OEHHA, 2011). Chromium ingestion has been associated with respiratory tract irritation and may lead to severe reproductive problems within men (ATSDR 2012). Nickel has been related to respiratory problems like chronic bronchitis, decreases function of lungs and also causes lung cancer.

Long time exposure or ingestion of antimony may cause serious health problems such as lung disease, heart problems, vomiting, stomach ulcers and diarrhea (Cooper, 2009).

Zinc is also an essential element required by human body. The acute toxicity caused by Zn in human includes vomiting, dehydration, drowsiness, lethargy, abdominal pain, nausea, lack of muscular coordination, and renal failure etc.
Manganese is an essential nutrient for human body but exposure to high level of Mn may cause manganism, a neurological disorder (Lars, 2016).

Copper is an essential nutrient for human body but exposure to high level of Cu can leads to severe mucosal irritation and corrosion, wide spread capillary damage, hepatic and renal damage and central nervous system irritation followed by depression(Krishnamurti,1991).

Physicians and scientists satisfied that no percentage of heavy metals in blood is safe or normal. Also, the exposure to extremely small amount may have long-term and significant effects in children while at the same time showing no characteristic symptoms. Once the heavy metals absorbed in the blood, part of them are filtered out and excreted, and the remaining are distributed in the liver, brain, kidney and bones and can affect the normal physiological functions of body cells and other organs.

The solution to this growing problem emphasizes on the permitted concentrations of these additives, unreacted monomers, especially heavy metals in food packaging plastic containers.

The aim of the present study is to assess the migration level of chemicals from plastic food containers into food under different simulating conditions as per guidelines.